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Preparation and properties of all solid-state electrochromic thermal control thin film

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Abstract

An all solid-state electrochromic thin film was designed to be used on thermal control of spacecraft. The structure of thin film is ITO/WO_3/Ta_2O_5/NiO/Ag/Glass. ITO, WO_3, Ta_2O_5, NiO and Ag thin films were prepared by magnetron sputtering method, and successfully produced all solid-state electrochromic thermal control thin film on substrate glass by magnetron sputtering. The tested properties of the thin film shows the result of 0.381, 0.490.

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1. Introduction

Electrochromic materials can change their optical properties under the action of an applied voltage，these materials can be made into different electrochromic devices(ECDs) based on their electrochromic properties[1].Fig 1 shows Basic structure of an electrochromic device[2].This device is light in weight, small of volume, low energy consumed and has highly controlled precision.It becomes possible to modulate the transmittance T, reflectance R, absorptance α, and emittance ε between widely separated extrema.

ECDs most prominent applications are in “Smart Window” for buildings on energy-savings, information display device, anti-dazzling rear-view mirrors for automotive and variable-emittance coatings for temperature control of spacecraft[3-6].

This thermal control technique has not been applied in China yet. In this paper, an all solid-state electrochromic thin film was designed to be used on thermal control of spacecraft. The structure of device is ITO/WO_3/Ta_2O_5/NiO/Ag/Glass，and the preparation and the properties of this thin film were studied.

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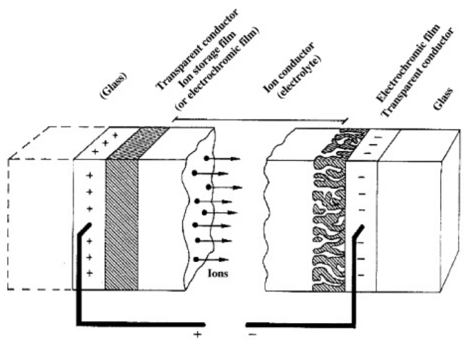

Fig 1 Basic structure of an electrochromic device

2. Experiment

Thin films of ITO,WO_3,Ta_2O_5,NiO and Ag were made by magnetron sputtering. The ITO transparent conducting thin films were grown by RF sputtering from an ITO target in an argon and oxygen environment .The distance between the target and the substrate was 15 cm. The power was 300W,the total gas pressure was 3.0 mTorr, and the O_2/Ar ratio was 0.05.Deposition temperature was about 25 ℃(room temperature).The sheet resistance of ITO thin film about 100Ω/sq. was achieved.

WO_3 electrochromic thin films were made by DC magnetron sputtering from a tungsten target in an argon and oxygen environment.The total chamber pressure was 5.0 mTorr. The power was 200W, and the O_2/Ar ratio was 0.25.Deposition temperature was about 400℃.

The Ta_2O_5 ion conductor (electrolyte) thin films were deposited by DC magnetron sputtering from tantalum targets in a 20% O_2 and 80% Ar environment. The chamber pressure was 3.0 mTorr. Deposition temperature was about 200 ℃.The power was 150W.

The NiO ion storage thin films were made by DC pulsed magnetron reactive sputter technique from metallic Nickel targets in a 20% O_2 and 80% Ar environment. The chamber pressure was 30 mTorr. Deposition temperature was 200 ℃.The power was 200W.

The Ag thin films were prepared by DC magnetron sputter from silver targets in a Ar environment. The chamber pressure was 3.0 mTorr. The power was 200W.

Lithium insertion was accomplished by conventional electrochemical method. Fig. 2 shows the schematic of experimental facility.The electrolyte used was 1M solution of water-free lithium perchlorate in propylene carbonate ($LiClO_4$–PC).A DC voltage of 1.0~3.0V was applied between the copper strip and Ag thin film on the electrochromic device.

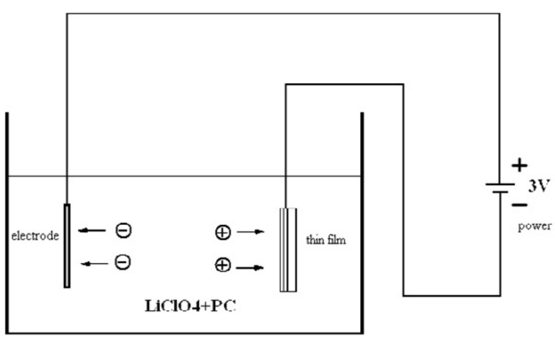

Fig 2 schematic of experimental facility

Reflectance measurements were carried out using an UV/VIS/NIR spectrometer(Type Lambda 900 from Perkin-Elmer) and Fourier transform infrared reflection (FTIR) spectrometer(Type System 2000 from Perkin-Elmer).

3. Results and discussion

The structures of electrochromic thin film are based on reflectance modulation. The calculations for the thin film devices were done by reflectance spectrum.For a non-transparent material the emittance is given by 1 minus the reflectance of the thin film(1-R). The amount of the emittance relative to that of a 300 K blackbody of the thin film at their different states is given by equation 1[7].

$$\varepsilon = \frac{\int_{\lambda_1}^{\lambda_2} A(\lambda) E_b(\lambda,T) d\lambda}{\int_{\lambda_1}^{\lambda_2} E_b(\lambda,T) d\lambda} = \frac{\int_{\lambda_1}^{\lambda_2} (1-R(\lambda)) E_b(\lambda,T) d\lambda}{\int_{\lambda_1}^{\lambda_2} E_b(\lambda,T) d\lambda} \quad (1)$$

where R(λ) is the reflectance and $E_b(\lambda,T)$ is the blackbody spectral emittance, the temperature T was 300 K, wavelength λ_1 was 2.5μm, and λ_2 was 25μm.Fig 3 shows a 300 K blackbody spectral emittance. Fig 4 shows the measured IR absorptance(A(λ)=1-R(λ)) of electrochromic thin film at different states. IR emittance was calculated according to equation (1), the result was:Δε=0.490 (0.294～0.784).

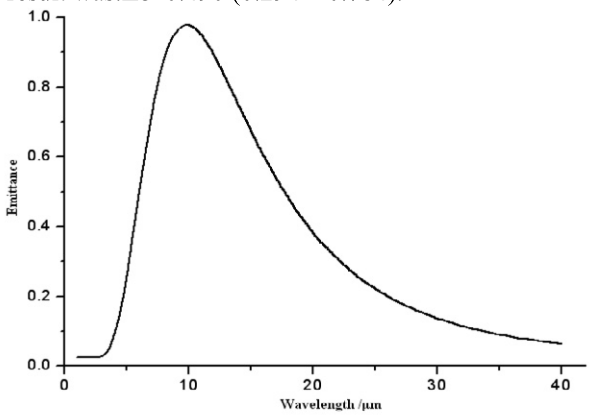

Fig. 3 Emittance of a 300 K blackbody

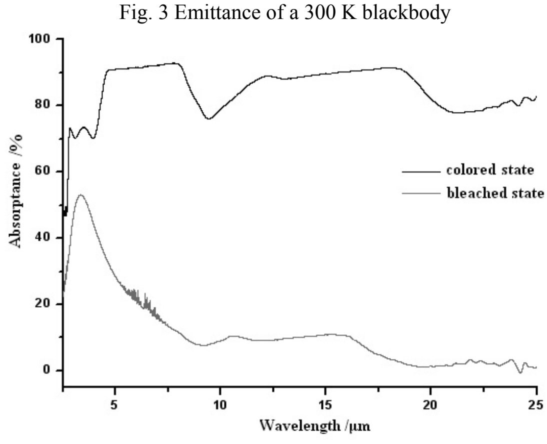

Fig. 4 The IR absorptance of electrochromic thin film at different states

For a non-transparent material, the absorptance(α) is also given by equation (2),The solar absorptance(αs) is given by equation (3).

$$\alpha(\lambda) = 1 - R(\lambda) \quad (2)$$

$$\alpha_s = \frac{\int_0^\infty \alpha(\lambda) E_s(\lambda) d\lambda}{\int_0^\infty E_s(\lambda) d\lambda} \quad (3)$$

$$\alpha_s \approx \frac{\int_{200nm}^{2500nm} \alpha(\lambda) E_s(\lambda) d\lambda}{\int_{200nm}^{2500nm} E_s(\lambda) d\lambda} \quad (4)$$

where R(λ) is also the reflectance and $E_s(\lambda)$ is the solar radiation intensity(Fig. 5).

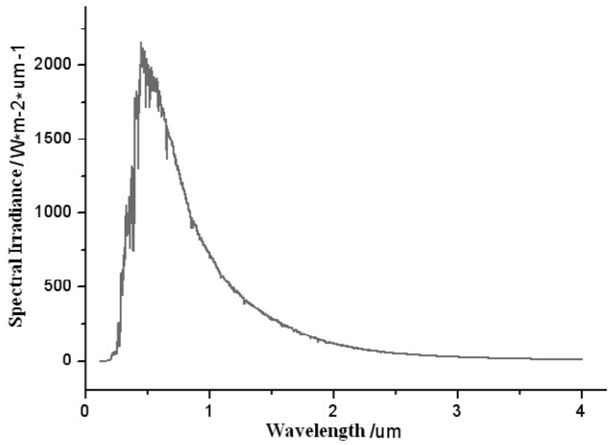

Fig. 5 Solar radiation intensity

Because most energy of solar radiation is at shorter wavelengths(from 200nm to 2500nm).So The solar absorptance can de nearly amount to equation (4).

Solar absorptance of electrochromic thin film was calculated.The change in value of Solar absorptance is 0.381,and corresponding solar absorptance were 0.594 and 0.213 at colored and bleached state respectively(Fig. 6).

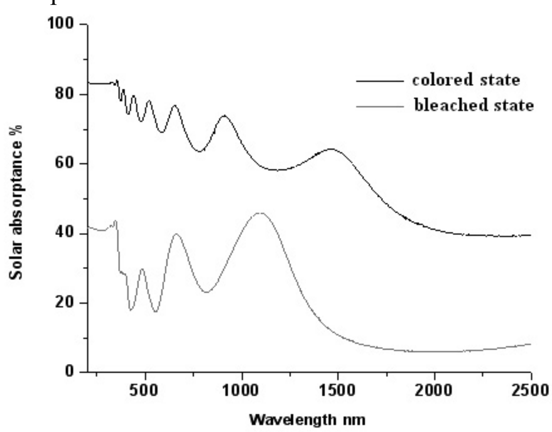

Fig. 6 Solar absorptance of electrochromic thin film at colored and bleached state

4. Conclusion

An all solid-state electrochromic thin film was designed to be used on thermal control of spacecraft. The structure of device is ITO/WO_3/Ta_2O_5/NiO/Ag/Glass. ITO, WO_3, Ta_2O_5, NiO and Ag thin films were prepared by magnetron sputtering method, and successfully produced all solid-state electrochromic Thermal control thin film on substrate glass by magnetron sputtering. The tested properties of the thin film shows the result of $\Delta\alpha_s = 0.381$， $\Delta\varepsilon = 0.490$.

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